Assessment of Fuel Cells as Auxiliary Power Systems for Transportation Vehicles

DE-FC04-01ALL67604

2003 Hydrogen and Fuel Cells Merit Review Meeting

Berkeley, CA

May 19-22

TIAX LLC
Acorn Park
Cambridge, Massachusetts
02140-2390

Reference: D0036.00

As auxiliary power units (APUs), fuel cells may find opportunity for automotive-volume markets by offering some key potential advantages.

- Fuel Cell Technology could be ideal for APU on trucks and other vehicles due to the following advantages:
  - minimal emissions
  - quiet operation
  - minimal vibration
  - high efficiency
  - compact design
- Several designs / demonstration units have been built:
  - BMW/International Fuel Cells 5-kW hydrogen-PEM demo for 7-series passenger car
  - DaimlerChrysler/Ballard 1.4-kW hydrogen-PEM demo for Freightliner Class 8 heavy-duty truck cab
  - BMW/Delphi/Global Thermoelectric 1 to 5-kW gasoline SOFC technology development program

APU applications can provide entry markets for fuel cell technology at cost levels significantly higher than that of propulsion applications.

The overall objective is to determine the viability of PEM & solid oxide fuel cells in the application of APUs for on-road vehicles.

- The USDOE Vehicle Technologies Program of the Office of Energy Efficiency and Renewable Energy objectives are:
  - Assess viability as defined in terms of achieving performance & cost targets:
    - Fuel flexibility
    - Start-up time
    - Power level
    - Duty cycle
    - Overall vehicle efficiency
    - Weight and volume
    - First and O&M cost
    - Reliability, Maintainability
  - Determine R&D needs and possible USDOE roles based on projected benefits to the Nation:
    - Barrels of oil displaced
    - Criteria pollutants avoided
    - Safety & Noise
  - Compare performance of fuel cell APUs with alternative approaches (both performance & cost)
  - Estimate benefits to the Nation and also for acceleration of fuel cell market introduction
  - Determine development & commercialization timeline and R&D gaps

DOE is particularly interested in how fuel cell APUs can help facilitate the introduction of fuel cells for propulsion or hybrid electrics.

We are developing detailed conceptual designs for 3 fuel cell/APU systems for on-road transportation applications.

1 Kick-off

- Summarize PEM and SOFC performance parameters

2 Identify & Select APU Systems

- Determine most promising future APU applications
- Refine likely duty cycles, power requirements, volume/weight targets

3 Develop Design Concepts

- Conceptual designs of 3 fuel cell /APU applications
- Conceptual design of interfaces with vehicle
- Compare conceptual system with competing technology

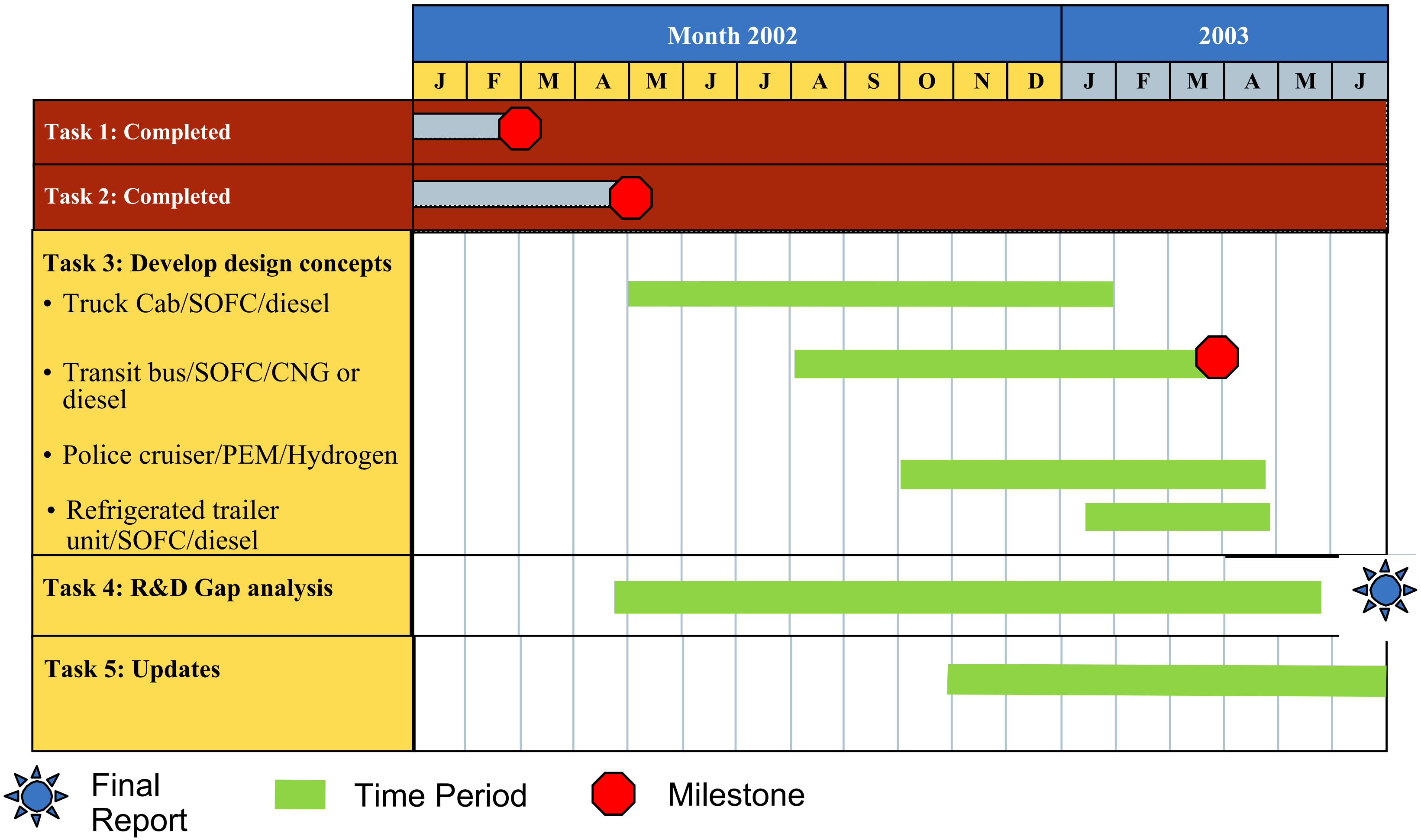
4 R&D Gap Analysis

- Determine gaps among fuel cell cost & technical performance and market needs
- Layout required development efforts

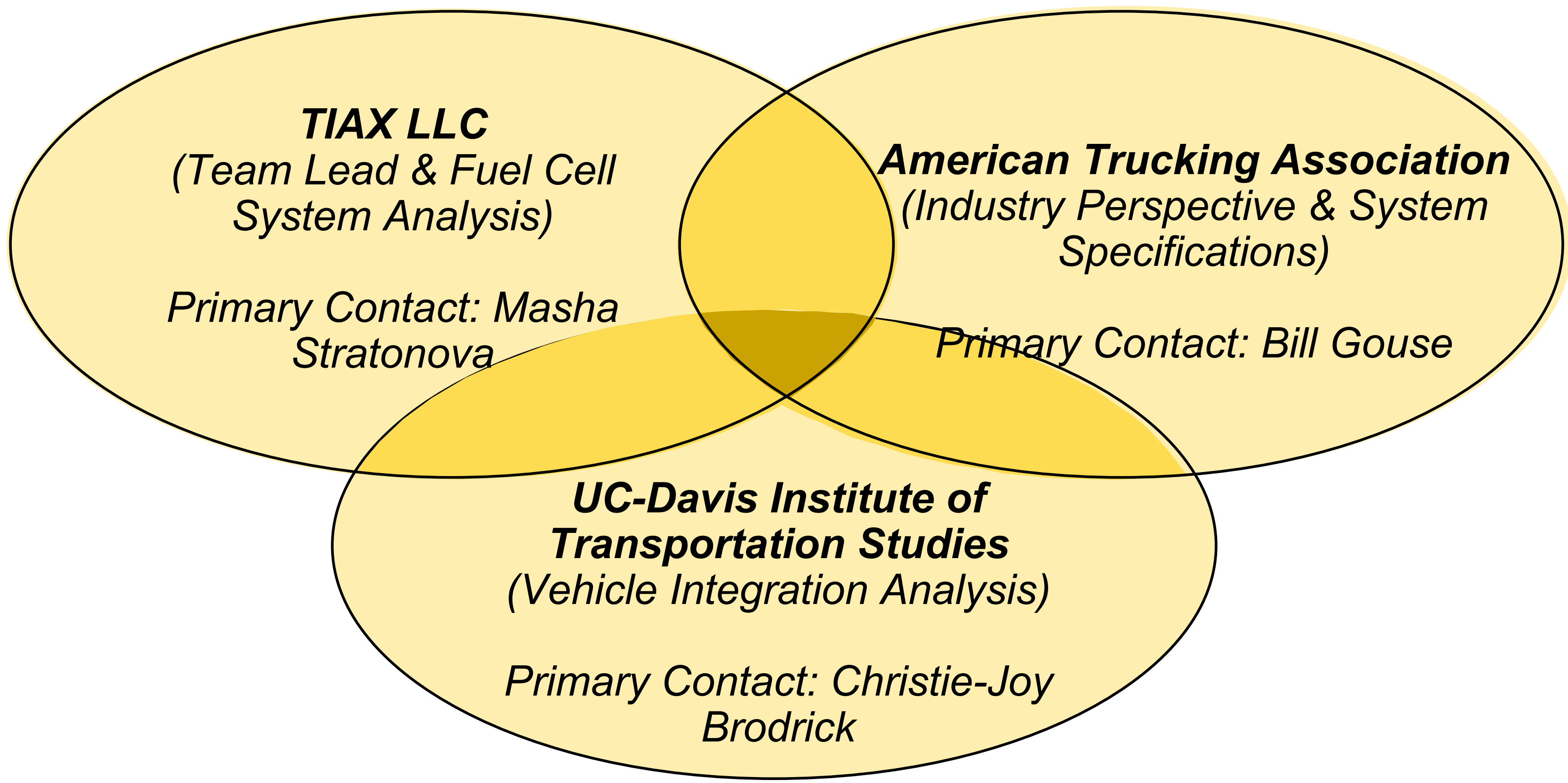
5 Analysis Update

- Update with latest publicly available data

Our current effort is to finalize conceptual designs of APUs and complete R&D gap analysis.



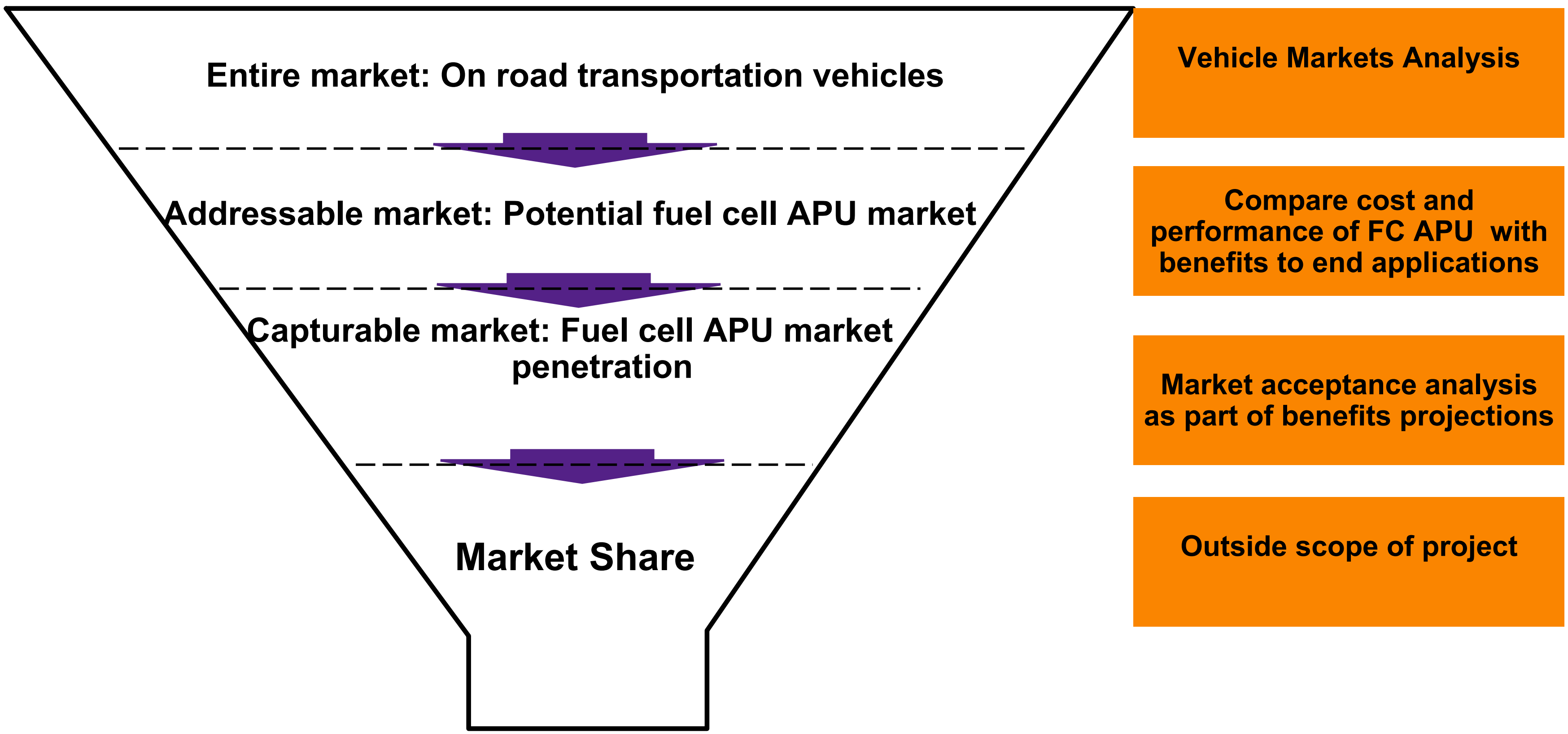
The DOE APU Fuel Cell Study Team consists of TIAX LLC and the University of California-Davis with input from the American Trucking Association.



We analyze PEM and planar, anode-supported SOFC for APUs based on an evaluation of the most important system characteristics.

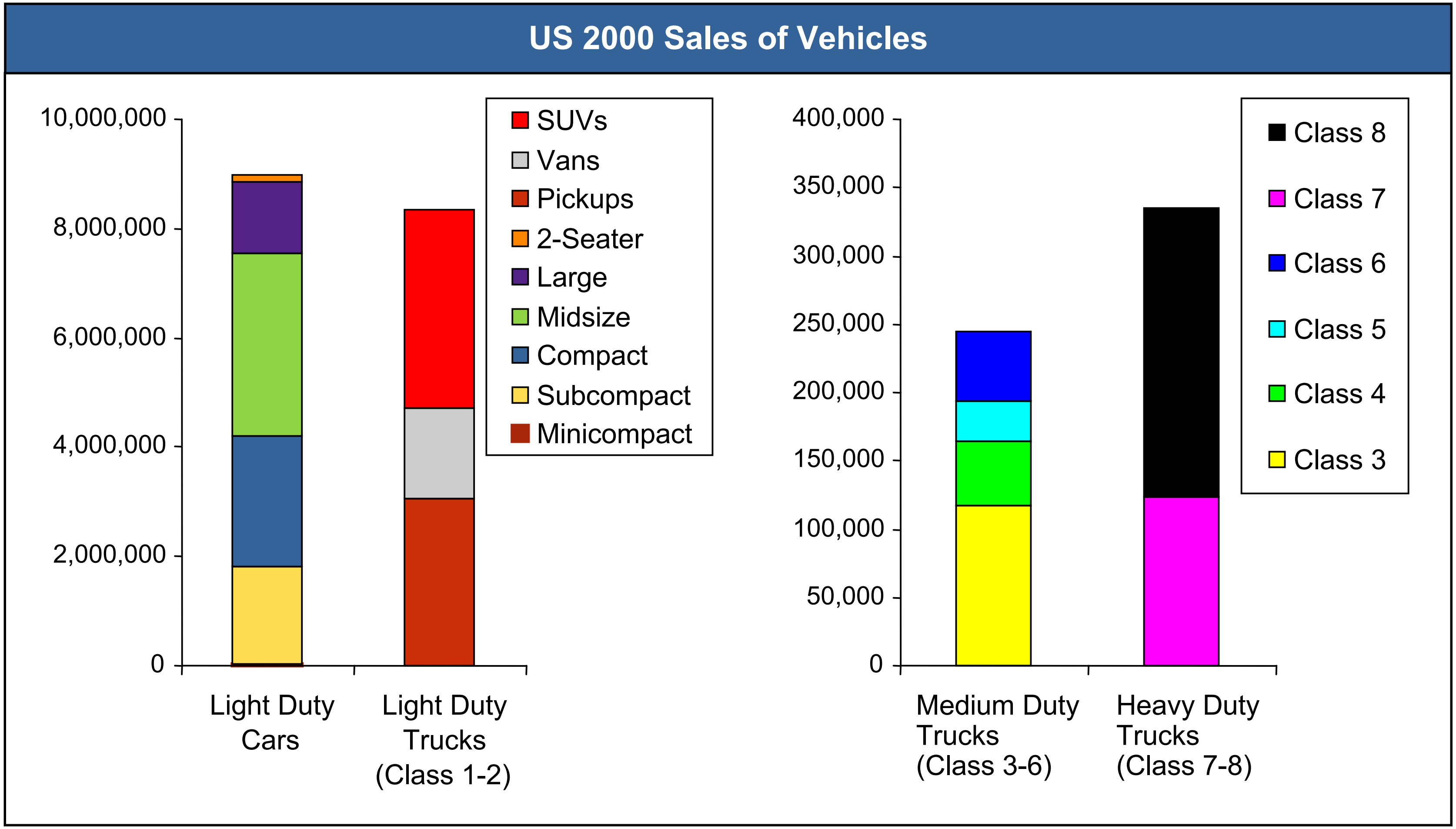
- Solid Oxide Fuel Cell technology is most promising for most APU applications
  - High power density
  - High efficiency
  - Most compatible with diesel fuel operation (used as primary engine fuels in target heavy duty vehicle markets)
- Fossil Energy SECA program and industry is developing core planar solid oxide technologies applicable to both transportation and stationary applications.
- PEM technology was selected for applications in vehicles for which hydrogen was assumed to be the primary fuel.
  - PEM APUs operating on fuels other than hydrogen were not considered.

We use a market screening methodology to identify the likely addressable market for on-road transportation applications



total market capacity **x** % market addressable **x** Market penetration (% captured) **x** % market share **=** # installed capacity

For the entire market assessment and the initial screening, we considered market size for new vehicles and price of vehicle.



We also considered RVs, utility trucks and miscellaneous segments.

Vehicles meeting market and cost criteria are considered as a potential fuel cell APU market.

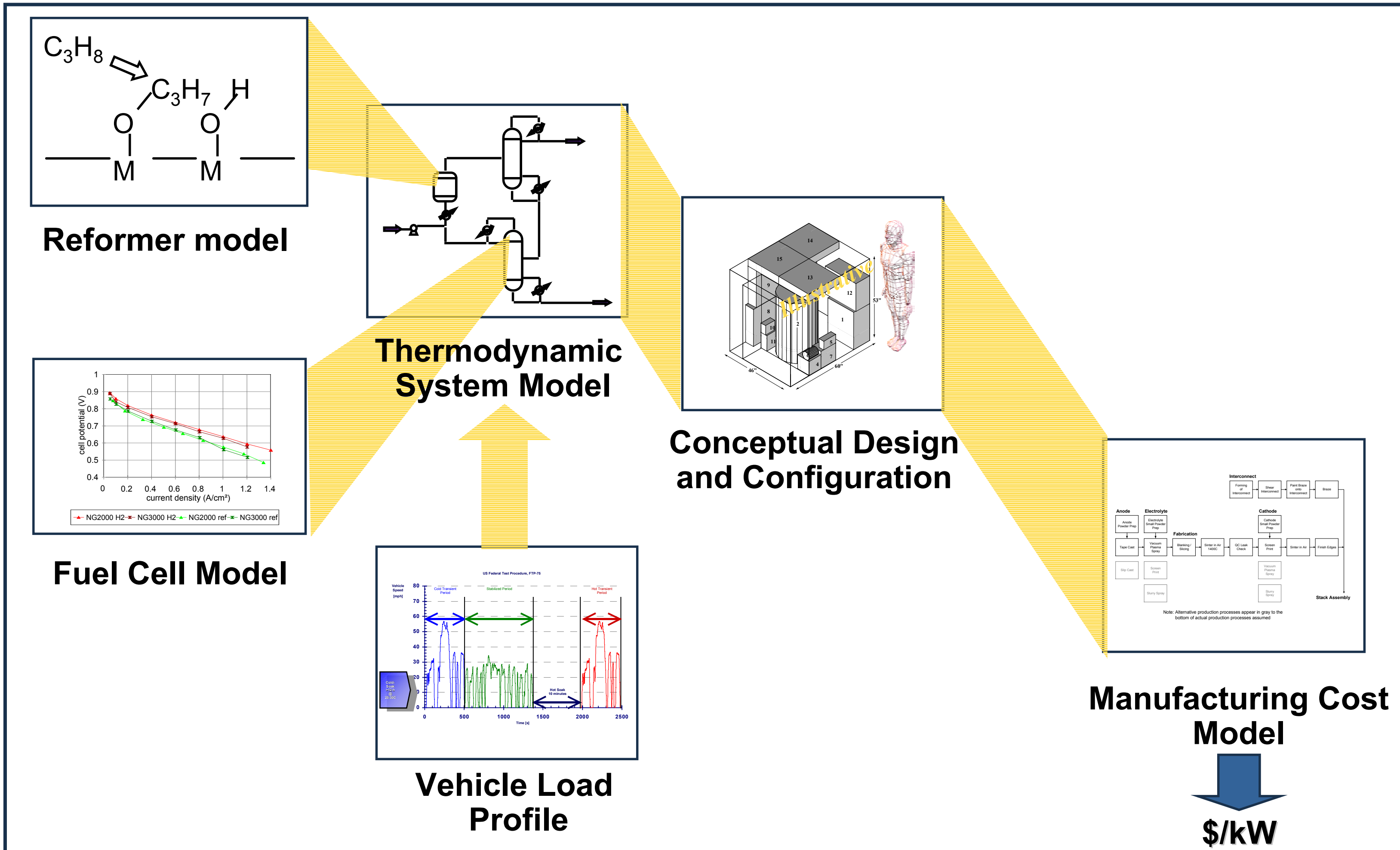
Market Segment	APU Power & Packaging Constraints		
	Required power (kW)	Maximum allowable weight (kg)	Maximum allowable volume (L)
Long-haul heavy-duty truck	3-6	*125*	*250*
Refrigeration trailer units	10-30	*125*	*250*
Specialized utility/PTO trucks	4-75	*400*	*250*
Transit, intercity buses	10-20	*100*	*200*
Recreational vehicles	2-7	*250*	*250*
Deluxe contractor truck	5-20	*250*	*250*
High-end passenger vehicles	1-3	*<50*	*<50*
Law enforcement vehicles	1-3	*<50*	*<50*

NOTE: Some values are based on estimates from personal communication with one or more sources, but are not conclusive. Weight and volume estimates are calculated from current space available for these systems and from PNGV research

Based on the economic marketability, technical feasibility, and potential benefits, four applications were chosen for detailed analysis.

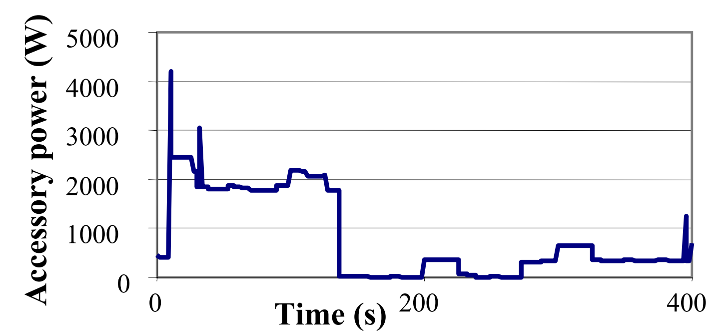
Heavy-duty truck sleeper cab	• Diesel fueled SOFC APU • APU provides for hotel loads and telematics while the truck is parked • Reduction in fuel consumption, emissions, noise; improved safety
Transit bus/motor coach	• CNG or Diesel fueled SOFC APU • APU provides for air conditioning and other electrical loads for passenger amenities • Potential fuel savings, emission reductions and noise reduction
Hydrogen fueled police car	• Compressed hydrogen fueled PEM APU • Electrical accessory loads • Reduction in fuel consumption, emissions, noise; improved safety
Refrigeration trailer unit	• Diesel fueled SOFC APU • APU provides cooling load • Potential fuel savings, emission reductions and noise reduction

We are applying our multi-subsystem modeling methodology to design the conceptual fuel cell APU systems.



During stationary cycle, potential benefits for 4-kW SOFC APU to power sleeper cabs include significant fuel and emissions saving.

Accessory Load Profile at Idle



	Fuel (gal/yr)			NO_x (ton/yr)	PM (ton/yr)
Idling Mode	Light	"Typical"	Heavy	"Typical"	
Main Engine Idling	936	1,548	2,160	0.147	0.002
4-kW SOFC APU	180	288	468	~ 0	~ 0
Saving at Idle	756	1,260	1,692		
	80.8%	81.4%	78.3%	>99%	>99%

Note: Light – 600 rpm, 1 kW average accessory load; "Typical" – 860 rpm, 2 kW; Heavy – 1150 rpm, 3.5 kW
Values shown are for average idling duration (6 hrs/day)
Approx. 15-20% of market idles <2 hrs/day, 60-70% from 2-10 hrs/day, and 15-20% >10 hrs/day

Preliminary analysis of the APU system for long-haul trucks indicates a payback period of under 2 years resulting from annual fuel cost savings.

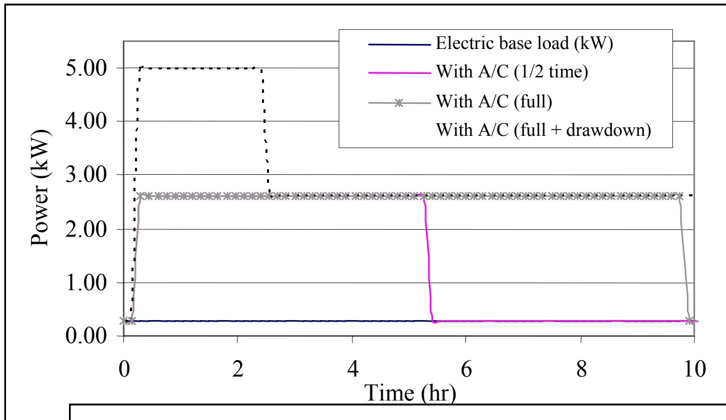
Economic Assumptions	
4-kW SOFC APU, installed package (Long-term cost assumption)	$580/kW
Diesel fuel cost	$1.7/gal

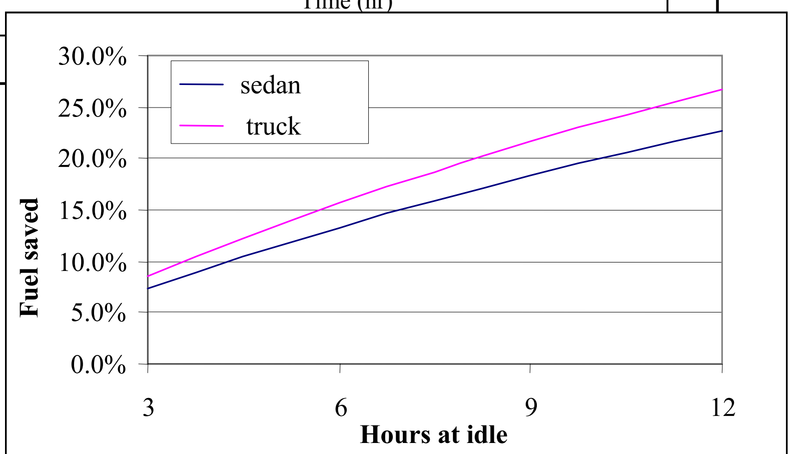
Application	Hours of Idling (hrs/yr/vehicle)	Annual Fuel Savings (gal)	Annual Fuel Cost Savings ($/yr)	Unit Cost ($)	Payback Period
Long Haul Trucks	1800-3000	900-2200	1530-3740	2,320	**0.6-1.5**

The low payback periods is likely to ensure a significant market penetration for the long haul truck applications.

Hydrogen-fueled PEM APU for police cars was considered with an assumption that hydrogen infrastructure is available.

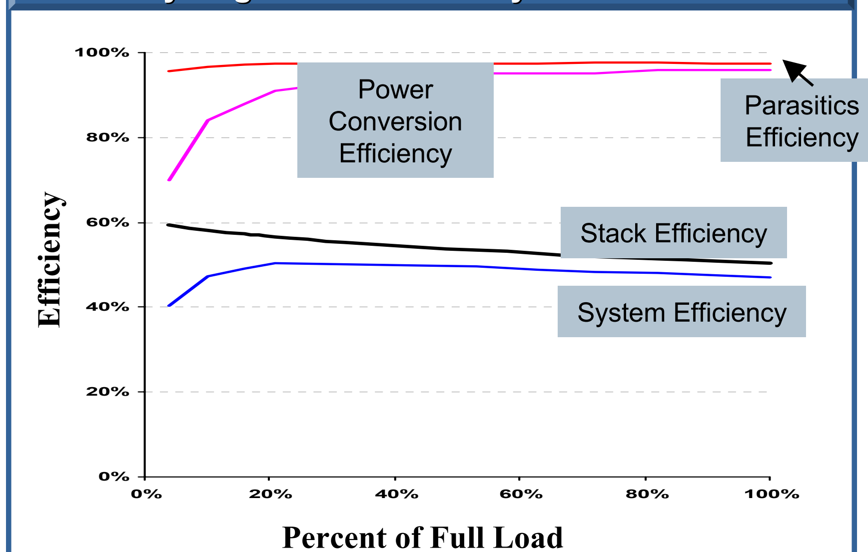
Simplified Electric Load Profiles at Idle





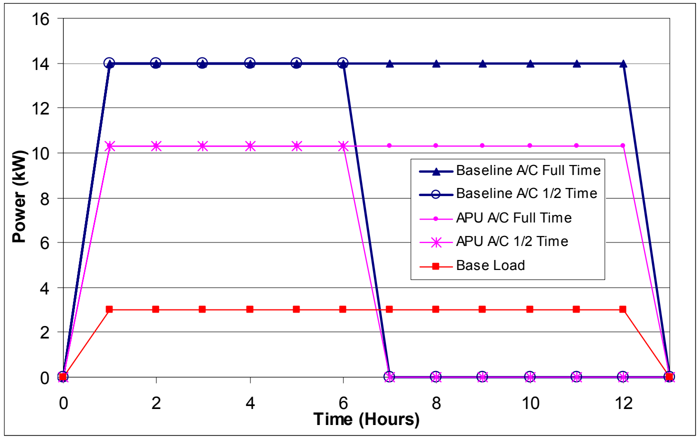
Note: Fuel saving estimate is based on gasoline equivalent.

5 kW Hydrogen Fueled PEM System Performance



Use of an APU in a transit bus does not lead to fuel saving benefits and only insignificantly reduces NO_x and particulate matter emissions.

Simplified Electric Load Profiles



	Engine Only	SOFC	Engine w/SOFC	Engine+SOFC	Reduction
Fuel	gal/h	gal/hr	gal/hr	gal/hr	%
Base load	3.5	0.23	3.4	3.6	**-2.1**
AC full time	4.2	0.91	3.4	4.3	**-1.2**
NO_x Emissions	g/mile	g/mile	g/mile	g/mile	%
Base load	24.6	0	23.2	23.2	5.8
AC full time	31.5	0	23.2	23.2	27
PM Emissions	g/mile	g/mile	g/mile	g/mile	%
Base load	0.3	0	0.3	0.3	1.1
AC full time	0.3	0	0.3	0.3	1.9

Fuel cells APUs offer benefits in high-volume markets and a possible near term channel for development of the technology.

- Fuel cell auxiliary power units can, in principle, be adapted to a range of non-propulsions applications for a number of applications including trucks, refrigerated trailers, law enforcement vehicles
- Several technology challenges must be overcome by both PEMFC and SOFC for widespread applicability as APUs
- Achieving a low manufacturing cost will be critical for broad SOFC and PEMFC commercialization